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Lifetime of the CDF Silicon Detectors Using Bias-Scan Data

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Outline of the talk

- Introduction: silicon detectors at CDF.
- Aging and performance of detectors.
- Biasing the detector and definition of Depletion voltage.
- Studies of performance at CDF.
- Bias-Scan results.
- Conclusions.

Monitoring the detectors: Aging

Precision measurement only achievable with high performance: good alignment, detailed control of sensor behaviour,...

- ⇒ too many channels for such small size always a challenge.
- ⇒ sensors exposed to high radiation due to the short distance to the beam.
- ⇒ sensitive to beam incidents (due to short distance).
- ⇒ Maintenance is hard (reparation of some problems almost impossible) due to lack of access to the subdetectors.

The main effect/trouble for monitoring the detectors is AGING: radiation effects will eventually destroy the performance of the detectors.

Aging is especially bad at the Tevatron since the current detectors were designed and built to last for Run IIa (2-3 fb $^{-1}$) only.

However, we have to use them along Run IIb too:

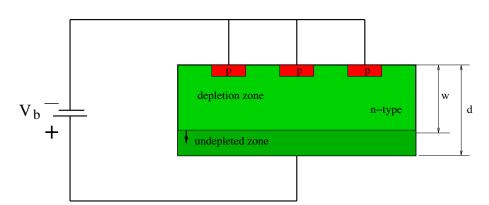
- ⇒ Detectors will have to work longer than expected.
- ⇒ They will have to work after suffering much more radiation.

Monitoring the aging and being able to extrapolate the behaviour in the future is a complete priority, and it will stay like that during the rest of the run.

Depletion voltage and performance

- Using doped silicon of different types it is possible to create pn-junctions that provides a depleted region in which the electron-hole pairs do no recombine but rather drift along the electric field lines.
- The size of the Depletion volume may be artificially modified by applying a reversed bias voltage following the equation:

$$w=\sqrt{2\epsilon
ho\mu V_b}$$



being ϵ , ρ and μ intrinsic parameters of the sensor (independent of the voltage or the depletion volume).

- ullet The ideal operation point is obtained with a voltage giving w=d.
- Radiation effects modify the electron-hole structure of the bulk:
 - **⇒** pn-junction evolves and eventually disappear with time.
 - ⇒ performance of the sensor degrading with time: AGING.

The dependence with time of the depletion voltage for the radiated sensors eventually requires higher and higher voltages to be fully depleted.

Monitoring the performance

It should be noted that the performance does not depend only on the ability of depleting the sensor, but also in how ideal is this operation point.

The typical figure of merit is the S/N ratio which measures the relative size in collected charge for an actual signal (i.e. charge induced by a crossing charged particle) to the intrinsic noise.

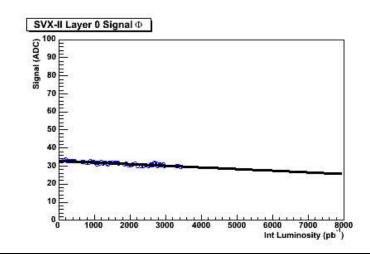
We compute this ratio by measuring the noise and the average signal in the verious sensors.

For NOISE:

We use calibration runs taken every two weeks
Increase with square root of luminosity.

For SIGNAL

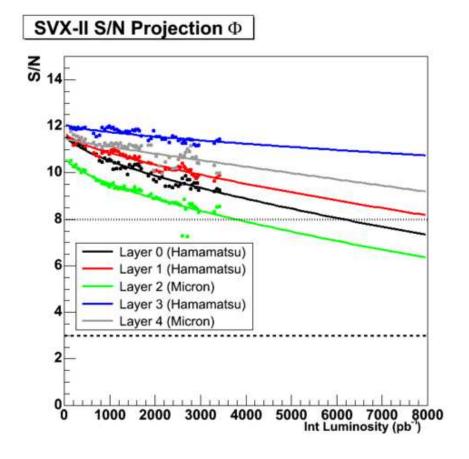
Hits associated to tracks from $J/\psi o \mu \mu$ Slow linear decrease with luminosity



Measuring S/N ratio

 \Rightarrow Studies show that most of the silicon layers will make it to the end of the the Run II. The innermost layer of the SVX will require careful monitoring to understand the chances to have it working beyond 4/5 fb⁻¹.

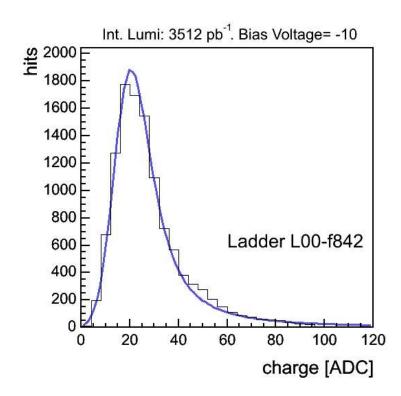
- \Rightarrow Limit at 8 is (guessed) limit for good trigger performance. In Run I, high- p_T b-tagging was realistically good with S/N ~ 3 .
- ⇒ On the other hand, extrapolation based on S/N ratios assume that the operational point is optimal (i.e. operation with fully depleted sensors).



Because of this, monitoring the evolution of the depletion voltage is a fundamental part to estimate how long the CDF silicon detector will last and how well it is performing.

Measuring the Depletion Voltage (I)

- Since charge collection is maximal for a fully depleted sensor, studies of the charge collection allows the study of the depletion voltage.
- For each particular sensor, we measure the amount of charge collected for the hits attached to tracks (reconstructed without using hits in the sensor under study).



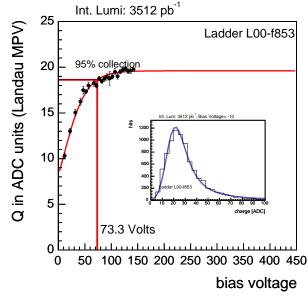
- ⇒ The amount of charge follows a Landau distribution.
- ⇒ The distribution is naturally smeared by the intrinsic noise.
- ⇒ Fitted curve is a Landau convoluted with a Gaussian (4 parameters) to have the most precise description.

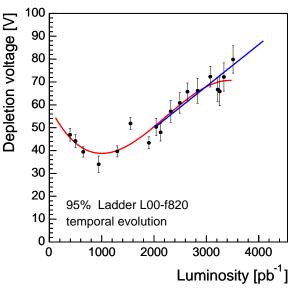
- This distribution is sensitive to the size of the depleted region.
- We use the maximum of the fitted curve (MPV) to quantify this dependence.

Measuring the Depletion Voltage (II)

This method provides information on the Depletion Voltage when we study the dependence of MPV as a function of the applied voltage.

- We measure this dependence by performing "Bias Scans" by applying different bias voltage to the sensors during data taking.
- Time-consuming process (usually 3 hours) done at the end of stores (1 every 6 weeks).
- Dependence is parameterized with a sigmoid.
- We define "Depletion Voltage" as the voltage for which the charge reaches 95% of the asymptotic value.
- With all the scans we have performed, we measure the dependence of the so-defined Depletion Voltage as a function of the integrated luminosity.
- Using a 3-degree polynomial (Red curve) to parameterize the global behaviour (and estimate the inversion point).
- Using a lineal fit (Blue line) after the inversion point to extrapolate to the future.

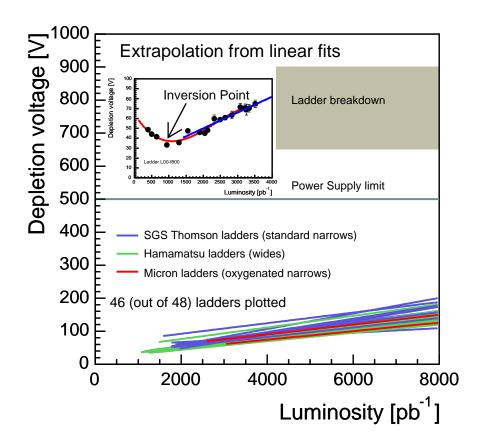




Current status for L00

Using the linear fits we extrapolate to the future for all the working sensors (ladders) of the L00 detector.

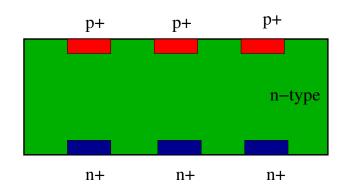
Different behaviour observed depending on the type of ladders. As expected, the oxygenated ladders inverted much later (larger radiation hardness).



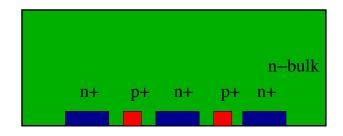
We should be able to deplete the L00 sensors up to the end of Run II without any troubles.

Double-sided detectors

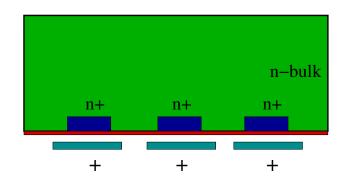
Since charge carriers drift in the two directions, we may be able to collect the charge on both sides of the sensors and measure a second coordinate of crossing using strips in a different direction.



We need to put some p-strips in between the n⁺ strips to prevent the horizontal charge spread (due to the lack of a depleted junction).



Other alternative is to put "field plates" (metal over oxide) over the n^+ -strips and apply a potential to repel the electrons.



In CDF the sensors in SVX and ISL are double-sided (information on ϕ and z).

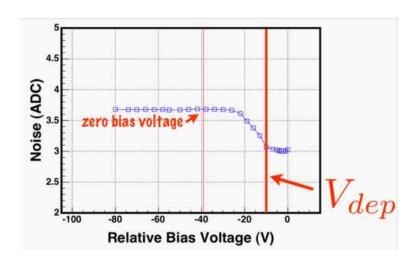
Noise as a function of the depletion voltage

Since the depleted region "grows" from the pn junction, the region close to the charge collectors in the back plane is not in a "depleted state" until the sensor is fully depleted.

In a double-sided detector the noise as measured in the back-plane strips drops very quickly as a function of the bias voltage in the region close to the depletion voltage (that we define as the 95% reduction between the plateaus).

It is possible to measure the depletion voltage from the dependence of the noise with the bias voltage (which do not require to spend beam time for the measurement).

After the inversion point, this method does not Work any longer because the change in the type of the bulk modifies the way the depleted region is generated as the bias voltage increases, and the dependence of the detected noise to the bias voltage is much reduced.

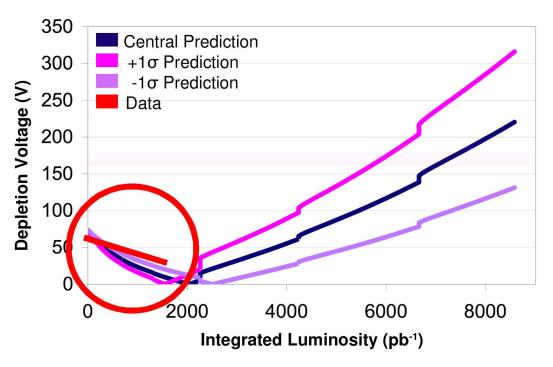


After the inversion point, the plan is to use the signal-to-bias scan to monitor the evolution of the Depletion voltage and the expected increase.

Results for SVX-L0 from the noise-to-bias scans

Using the same method as for the "signal-to-bias" method, we may study the evolution of the depletion voltage as a function of the collected luminosity.

Results are in good agreement with the expectation, but method is not reliable close to inversion.



Prediction: S. Worm, "Lifetime of the CDF Run II Silicon," VERTEX 2003

We plan to update this plot with the signal-to-bias data as soon as posssible.

Concluding remarks

- The CDF silicon detectors have been operating in a high radiation environment during a long time.
- Providing nice physics from Tevatron collisions in extreme conditions.
- Innermost layers of silicon already in Inversion Regime.
- Periodic signal-to-bias and noise-to-bias scans of the silicon detectors have become an usual monitoring tool for the CDF silicon
 - ⇒ Evolution of the depletion voltages extrapolated to the future.
 - ⇒ Checking bias voltages are high enough to keep sensors depleted.
 - ⇒ Results for L00 provide information on lifetime of the detector.
- Current extrapolation gives us confidence that even the most innermost layers of silicon will be operated to the end of the run (2009 or even 2010).
- We will be able to deplete sensors during the whole run (for L00 and most of SVX layers).
- Monitoring of the S/N ratio confirms optimistic view about the future of the silicon performance.
- These studies provide useful information for the silicon detectors in the LHC.